New insight into the Quaternary evolution of the River Trent, UK

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Abstract
An exhaustive review of geological, palaeontological and archaeological data, coupled with selected new research and dating programmes using optically stimulated luminescence and amino acid racemization, has provided new insights into the origin and Quaternary evolution of the Trent river system. An important component of the new research was uplift/incision modelling based on the river-terrace archives from the greater Trent system, but also including dated speleothems in the southern Pennine valleys. The Trent came into existence following the Anglian (MIS 12) glaciation as a river draining the Dove, Derwent and Soar catchments via the Lincoln Gap and the newly eroded Fen Basin. Prior to that glaciation much of what is now the Trent catchment was drained by the Bytham system, which had its main axis significantly further south and flowed to the North Sea via East Anglia. Eastward Middle-Trent drainage from Derby to Nottingham only began with deglaciation of MIS 8 (Wragby glaciation) ice, which reached at least to the lower Soar and the Fen Basin. The widespread preservation of MIS 7 interglacial deposits in the Lower Trent and in Fen Basin valleys implies that no subsequent glaciation affected these areas. Late Devensian (MIS 2) ice reached the uppermost and lowermost Trent, possibly effecting diversion of the river into the Yorkshire Ouse, following overflow and subsequent emptying of Glacial Lake Humber.

Keywords:
River Trent; River terraces; MIS-8 glaciation; Bytham River; Lake Humber; uplift

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1. Introduction

With a catchment at the southern limit of repeated lowland glaciation during the late Pleistocene (Fig. 1), the Trent is one of the most northerly rivers in Europe to have an extensive archive of river terraces and associated biostratigraphical and archaeological evidence. Such was the rationale for the 'Trent Valley Palaeolithic Project' (TVPP; see acknowledgements), which provided the opportunity for an extensive modern study of the Trent sequence and its palaeontological and Palaeolithic archives, as well as a critical review of past research (Howard et al., 2007; White et al., 2007a; Bridgland et al., 2014; Rose, ~~this volume/~~2015; Westaway et al., ~~this volume/~~2015). As well as fieldwork in those gravel pits active in 2003–6, together with temporary excavations at important localities identified from past research, the TVPP funded new dating programmes using the optically stimulated (OSL) and amino acid racemization (AAR) methods (Schwenninger et al., 2007; Penkman et al., 2011, 2013; Bridgland et al., 2014; Table 1). In the latter case the analyses made use of *Bithynia tentaculata* opercula from TVPP sites and from archived collections. A key aspect of the study was the review of the archaeological (artefacts) collections held in museums across the UK, with the aim of using project findings to provide a more secure context for human occupation of the Trent during the Lower and Middle Palaeolithic (cf. White et al., 2009).

Key to understanding the evolution of this system is the influence on Trent drainage of three distinct glaciations: (1) Britain's most extensive, during the Anglian (MIS 12), (2) the last (Late Devensian, MIS 2) glaciation, when ice reached the uppermost and lowermost parts of the Trent catchment, and (3) a more enigmatic glaciation between 1 and 2 that can be shown to have occurred during MIS 8 (White et al., 2010). All three glaciations caused important changes in the drainage pattern of the English East Midlands, with the Trent as exists today (Fig. 1) being established in stages as the result of their cumulative effects.

Also included in the TVPP was a review of karstic evidence from cave systems in the Peak District, which, since it can be interpreted in terms of palaeo-watertable level, provides a well-dated archive of the progressive deepening of the Pennine tributary valleys of the Trent. Such data are comparable with the evidence from river terrace sequences but are available in areas where the latter have not formed (for example, because the bedrock is too durable for extensive lateral valley migration) or have been destroyed by glaciation. Data from both the terraces and the karstic systems were investigated by mathematical modelling of the uplift history represented, this uplift being assumed to be the driver for the aforementioned valley deepening (Bridgland et al., 2014; Westaway et al., ~~this volume/~~2015).

Full details of the evidence obtained and reviewed during the TVPP is provided by a project monograph (Bridgland et al., 2014); the intention of the present paper is to summarize and disseminate the new ideas about the Middle–Late Quaternary evolution of the Trent drainage system.

2. Early history: the Bytham River (Pre-Anglian)

The earliest evidence for drainage related to the modern Trent system is a suite of gravels and sands, demonstrably pre-dating the Anglian (Marine Oxygen Isotope Stage [MIS] 12) glaciation, that extends from the West Midlands, in the Stratford-upon-Avon–Coventry area, to Leicester, Melton Mowbray and into East Anglia via the Breckland and the Waveney valley (Rose, 1987, 1989, 1994; Lee et al., 2004, 2006; Westaway, 2009). These are the Bytham Sands and Gravels, attributed to the Bytham River, although they have also been given local names ('Baginton', 'Thurmaston' and 'Ingham', respectively) in the West Midlands (Shotton, 1953), the Leicester area (Rice, 1968, 1991) and East Anglia (Clarke and Auton, 1982, 1984). The course of the Bytham, which can be reconstructed from the distribution of these gravels, had its west–east axis significantly to the south of the modern Trent and extended across the present location of the Fen Basin and into East Anglia and the southern North Sea (Fig. 2). Its overlap with the modern Trent catchment is, however, considerable; the main Bytham occupied (and probably initiated) the valleys of the Upper Soar and its tributary the Wreake, and received precursors of the Derwent and Dove as left-bank tributaries (Brandon, 1995; Carney et al., 2001; Lee et al., 2006; Fig. 2). Furthermore, TVPP research suggests that a pre-Anglian river that drained at least part of the modern lower Trent catchment through the Ancaster Gap was a contemporary, and probably also a tributary, of the Bytham (Bridgland et al., 2014). This river is represented by high-level gravels north of the gap, with outliers to the west, and had a left-bank tributary of its own, recorded by a steeply-inclined string of gravel outcrops extending south-east from Caythorpe Heath (Bridgland et al., 2007; Figs 2, 3). This is the first time that a sedimentary record has been identified for an 'Ancaster River' (cf. Swinnerton, 1937; Clayton, 2000; Rose et al., 2001; Rose, 2009); the deposits were mapped by the British Geological Survey (BGS) as glacial but the observation that they lack local rocks from the escarpment (Berridge et al., 1999) is erroneous, since in the subsurface they are dominated by local limestones and are completely devoid of glacial indicator lithologies such as *Rhaxella* chert or northen exotic crystalline rocks (Bridgland et al., 2007, 2010, 2014; Table 2).

The credentials of the Bytham system as pre-dating the Anglian glaciation have recently been questioned by Gibbard et al. (2012a, b, 2013), who have suggested that the gravel deposits in the Midlands attributed to this river post-date the Anglian glaciation and that they represent drainage into the North Sea via the Fen Basin, rather than being linked with the 'Ingham Sand and Gravel' in East Anglia. However, at sites in the West Midlands, such as Waverley Wood Farm Pit (NGR SP 372718) and Pools Farm Pit, Brandon (SP 384763), interglacial deposits that are clearly integral to the Bytham sedimentary archive (contra Gibbard et al., 2013; cf.Westaway et al., ~~this volume/~~2015) have yielded abundant biostratigraphical evidence for an age in the late Cromerian Complex (Shotton et al., 1993; Maddy et al., 1994; Maddy, 1999; Coope, 2006; Keen et al., 2006), underpinned by amino-acid geochronology that also points to a pre-Anglian (MIS 13) date (Penkman et al., 2011, 2013). Furthermore, TVPP research has shown that a precursor of the Trent came into existence following the Anglian glaciation, draining through the Jurassic escarpment at Lincoln and into the Fen Basin (Bridgland et al., 2014; below), which is presumed to have been newly excavated by Anglian ice (Perrin et al., 1979; Clayton, 2000; Fig. 4). The suggestion, by Gibbard et al. (2012a, b, 2013), that the deposits in Norfolk interpreted as Bytham Sands and Gravels are of glacial origin is untenable for the same reason that applies to the high-level gravels near Ancaster: they lack the characteristic glacial indicator clasts, including *Rhaxella* chert (cf. Bridgland et al., 1995).

3. Initiation of the Soar–Trent following the Anglian glaciation

During MIS 12 the Bytham system was overrun by Anglian ice, which reached the valley of the Thames in Hertfordshire and Essex (Fig. 1), diverting the latter river (Gibbard, 1977, 1979; Bridgland, 1988, 1994) and essentially obliterating the former. Indications of subsequent Trent drainage configurations are scarce but important strands of evidence can be identified. First, high-level gravel capping Wilford Hill (~~NGR~~ SK 582352, at ~91 m O.D.) has long been interpreted as both glacially-fed and the highest terrace deposit of the Trent (Clayton, 1953; Figs 3, 5). Glacial indicators, particularly *Rhaxella* chert, crystalline lithologies and flint, were confirmed in TVPP analyses (Bridgland et al., 2014), reinforcing the interpretation of this outlier as outwash from Anglian ice, perhaps deposited during deglaciation in an emergent Trent system. Second, the depth of the 'Trent Trench', a remarkably straight gorge reach through Triassic bedrock between Nottingham and Newark (Figs 1, 5), indicates that the river has continually occupied this course since it first incised below the level of the Anglian deglaciation surface, represented hereabouts above the gorge sides; note that the sides of the gorge reach significantly greater heights than the projected Trent valley floor represented by any part of the 'Hilton Terrace complex' (cf. Fig. 3; Table 2). The cumulative incision, amounting to ~62 m, was matched to uplift since the Anglian by preliminary mathematical modelling (Westaway, 2007), although part of that uplift is probably attributable to Anglian glacio-isostasy (Bridgland et al., 2014). It should be noted that the Trent Trench has previously been interpreted as resulting from the marginal drainage alongside an ice sheet, by Posnansky (1960).

Further evidence for the configuration of the immediately post-Anglian Trent system is provided by the Hathern Gravel; known only from a borehole on the western flank of the Soar valley (Brandon, 1995, in Maddy, 1999; Fig. 1), this deposit is dominated by Carboniferous chert and limestone from the Peak District and seemingly represents a palaeo-Derwent. Its low level precludes interpretation as part of the pre-Anglian Bytham system, implying that the Derwent continued to flow southwards, after Anglian deglaciation, along what eventually became the northward-declining Soar valley. This reinterpretation of the Hathern Gravel requires that overlying glacial diamicton of Thrussington (western) 'facies' be attributed to a post-Anglian glaciation. The conclusion reached is that the early post-Anglian drainage system lacked a direct west–east valley between Derby and Nottingham, such that the Derwent flowed southwards to join the Soar south of Hathern. These two rivers, now the most important present-day tributaries of the Trent, were the main drainage arteries in the East Midlands at this time (Fig. 4).

Finally, a post-Anglian palaeo-valley has been identified between Lincoln and the Fen Basin, filled with till (the Wragby Till of Straw (1966)) that was hitherto generally thought to be Anglian, but, like that at Hathern, is now attributed to a later glaciation (see below). This palaeo-valley, reconstructed from borehole data, underlies the modern lower valley of the River Witham, which is known to have been inherited from the Pleistocene Trent (e.g., Brandon and Sumbler, 1988, 1991). Given that it had a markedly smaller catchment than the modern river, the early post-Anglian Soar–Trent (Fig. 4) would have had a steeper downstream gradient, taking it below the modern land surface east of Lincoln (Bridgland et al., 2014; Westaway et al., ~~this~~

~~volume/~~2015; Fig. 3). Whether its sediments survive at depth beneath the Witham valley is a matter for future investigation.

4. Late Middle Pleistocene glaciation and formation of the west–east Middle Trent valley

Early workers in the East Midlands were unanimous in recognizing a glaciation between those now classified as Anglian and Devensian (e.g., Clayton, 1953; Posnansky, 1960; Rice, 1968). Given that glacigenic deposits of different ages emanating from similar geological source areas can have identical characteristics, distinguishing between pre-Devensian tills is difficult without means of age determination. The TVPP has used the inter-relations between glacial and fluvial (terrace) deposits as an indication of age. In the lower Trent this led to the accepted Anglian age of the widespread Wragby Till to the east of the Jurassic escarpment being questioned, given its very low disposition and its relation to the late-Middle Pleistocene river terraces. Straw (1966, 1983, 2000, 2005) has consistently regarded this till as post-Anglian, although Lewis (1999) classified it as the Wragby Member of the Anglian Lowestoft Formation. TVPP findings place it in MIS 8, on the basis that it immediately underlies Trent sediments of unequivocal MIS 7 age, as established from biostratigraphy and amino-acid dating (White et al., 2010; Penkman et al, 2011; Bridgland et al., 2014). An age for this glaciation in MIS 10, as postulated for the Oadby till by Sumbler (2001), cannot be excluded unequivocally, although the absence of any MIS 9 interglacial deposits within the outcrop of the Wragby Till (or, indeed, anywhere in the Trent system) provides evidence (albeit negative evidence) in favour of MIS 8 (cf. Westaway et al., ~~this volume/~~2015). As was noted (in connection with the Hathern Gravel), it is contended that the Middle Trent was also glaciated at this time (Fig. 6) and that the modern west–east configuration of the Trent valley between Derby and Nottingham was established during MIS 8 deglaciation. It is evident that during this glaciation a lobe of eastern ice penetrated the Middle Trent, presumably by way of the Trent Trench, giving rise to till of Oadby 'facies' in the Elvaston and Swarkestone channels, part of a system of subglacial tunnel valleys that are also now attributed to MIS 8 (Figs 5, 6). This reinterpretation allows better reconciliation of the considerable depth of these channels below the reconstructed Anglian landscape (Fig. 3), as well as providing a potential explanation for the trough-like form of the Trent Trench (Bridgland and White, 2007). It should be noted that Straw (1983) envisaged 'Wolstonian' ice flow from the NE, across the Jurassic outcrop south of the Humber and extending to Nottingham and the Lower Soar valley.

Three separate terraces of the Middle Trent can also be ascribed to MIS 8 (Table 3; Fig. 7). The lowest of these, formed by the Etwall Sand and Gravel of the Middle Trent, represents a large part of the complex Hilton Terrace, as defined by earlier workers (cf. Clayton, 1953; Posnansky, 1960; Table 3). Two higher terraces in the Middle Trent are attributed to earlier parts of MIS 8, when ice remained in the region, their higher disposition within the modern landscape being the result of glacio-isostatic effects, perhaps with further influences brought about by course changes associated with MIS 8 deglaciation (Bridgland et al., 2014). The lower of these was renamed the 'Sandiacre Terrace' following the TVPP research; it was mapped in the Middle Trent by the BGS as the Eagle Moor Sand and Gravel, but that name is based on a Lower Trent type locality and was applied in that part of the valley to deposits forming a terrace with multiple facets, thought to represent both the Sandiacre and the Etwall terraces of the Middle Trent. At a still higher level in the Middle Trent are gravels and glacial sediments forming the highest parts of a complex of glacial deposits filling and overlying the aforementioned tunnel-valley systems in the Derwent–Trent confluence area, the Elvaston and Swarkestone channels (Figs 3, 4).

Evidence for what is here termed the 'Wragby glaciation' has also come from neighbouring valleys in the Fen Basin, where Langford (2004) described a meltwater channel and lacustrine deposits representative of a post-Anglian–pre-Devensian glaciation. White et al. (2010) suggested this was the same glaciation that formed the outwash delta at Tottenhill (Fig. 6), although the latter has been attributed to MIS 6 by Gibbard et al. (2009, 2012a, b). Those authors, however, have conflated pre-Anglian Bytham River gravels with the late Middle Pleistocene glacial outwash deposits, despite the very clear clast-compositional distinction between the two (see above; cf. Bridgland et al., 1995). The claim for an MIS 6 age is supported by OSL dating, although the details of this date have not been published (cf. Gibbard et al., 2009, 2012a, b); it is seemingly in conflict with the terrace sequence in the Nar valley, within which the Tottenhill outwash gravels would appear to represent MIS 8, there being three lower terraces, with the Ipswichian (MIS 5e) represented within the middle of these (cf. Boreham et al., 2010; Bridgland et al., 2014),

It seems most unlikely that there was an advance of eastern British ice during MIS 6 any further south, within the area currently onshore, than the Humber, since MIS 7 deposits have survived at Bielsbeck (SE 861378), in the valley of the Foulness, a north-bank Humber tributary (Schreve, 1999); the Bielsbeck sediments would seem to represent a rare (perhaps unique) survival of Middle Pleistocene deposits of the Yorkshire Ouse system. Protruding above later sediments of Devensian pro-glacial Lake Humber, the Middle Pleistocene remnant at Bielsbeck has narrowly avoided being destroyed by that most recent glaciation. Further south, in southern Lincolnshire and the Fen Basin, the widespread preservation of MIS 7 interglacial sequences (Langford, 2004; White et al., 2010) again argues against glaciation during MIS 6.

5. The 'Lincoln Trent'

The evolution of the Trent during the last two climate cycles is well understood, thanks to detailed work by the BGS, particularly in the reach downstream of Newark (Brandon and Sumbler, 1988, 1991; Figs 7, 8). This established new terrace formations, named 'Eagle Moor', 'Balderton', 'Scarle' and 'Holme Pierrepont', broadly equivalent to the Upper Hilton, Lower Hilton, Beeston and Floodplain terraces of Clayton's (1953) pioneering scheme. The TVPP has made only minor changes and has standardized correlations with sequences in the main tributaries, the Soar (cf. Rice, 1968) and Derwent (Bridgland et al., 2014; Table 3). Brandon and Sumbler's age model and their suggestions (1) that MIS 7 deposits occurred within basal parts of the Balderton Formation and (2) that the Eagle Moor and Balderton terraces continue into the Witham valley downstream of Lincoln as the Martin and Southrey terraces, respectively, have all been confirmed (Fig. 3; Table 3). Particularly important has been the discovery of interglacial deposits within the Balderton Formation at Norton Bottoms (~~NGR~~ SK 863588), near Newark, of clear MIS 7 age (White et al., 2007b; Penkman et al., 2011, 2013; Bridgland et al., 2014; Fig. 7).

6. The final diversion of the Trent to the Humber

The modern lower course of the Trent, by which it flows northwards to join the Yorkshire Ouse/Humber system, is clearly of geologically recent origin, since no terraces can be traced by this route, with the exception of the Holme Pierrepont (BGS DigMap). On the basis of borehole data, that terrace also continues into the Witham valley (Westaway, 2007), in common with the higher Lincoln-Trent terraces (Fig. 8). Dating the downcutting from the Beeston–Scarle to the Holme Pierrepont terrace, and the subsequent diversion to the Humber, is dependent on a range of (old and new) geochronological evidence, summarized in Table 1 (Bridgland et al., 2014). Also important is correlation of the two terraces recognized in the Upper Trent, both fed by outwash from the Late Devensian Irish Sea glaciation (Fig. 8), with those in the Middle Trent. If the higher of these Upper Trent terraces is equivalent to the Beeston, then downcutting to the Holme Pierrepont occurred during the Late Devensian glaciation; there is no evidence of glacial influence on the Scarle Terrace on the eastern side of England, but that conforms with the earlier dating of the Irish Sea Devensian ice lobe in comparison with the East Coast ice advance (Clark et al., 2012; Fig. 8). The balance of evidence indicates downcutting to the Holme Pierrepont terrace late in MIS 2 (~25 ka), with diversion to the Humber almost at the end of the Pleistocene, perhaps coincident with Devensian deglaciation. The latter reinforces the suggestion that southward overflow from Lake Humber into the Lincoln Trent formed the breach in the interfluve that allowed Trent diversion northwards by this route when the ice retreated and the lake drained (Bridgland et al., 2014; Fig. 8C–D). Bridgland et al. (2010) suggested that this diversion was assisted by isostatic effects related to deglaciation further north and the temporary development of a northward topographic gradient.

7. Synthesis and conclusions

Reinterpretation, following the TVPP studies, of the evolution of the River Trent system has important repercussions for landscape development and glacial history in Britain and Northwest Europe. Of particular importance was a poorly understood glaciation during MIS 8. Although recognized previously, particularly amongst glacigenic deposits given the name 'Wolstonian' (cf. Rose, 1985), this post-Anglian–pre-Devensian glaciation of the East Midlands and eastern Britain has hitherto generally been ascribed to MIS 6. However, the glacial–interglacial stratigraphy recognized in the terraces of the palaeo-Trent downstream of Lincoln shows that the glaciation there must have pre-dated MIS 7. Indeed, widespread biostratigraphical evidence for MIS 7 deposits in the northern Fenland and as far north as Bielsbeck (see above) would seem to make the occurrence of an eastern British glaciation south of the Humber during MIS 6 untenable.

The precursor of the Trent drainage system was the Bytham River, as recognized previously in the West and East Midlands and traced into East Anglia. The credentials of the Bytham, which was already receiving tributary drainage input from ancestral versions of the Rivers Derwent and Dove, as an entirely pre-Anglian system have been confirmed by TVPP studies. The Bytham system included a left-bank tributary draining the area east of Nottingham towards the modern Fen Basin, as recorded by high-level gravels capping the Jurassic escarpment, which represent the river that initiated the Ancaster Gap. During Anglian deglaciation the Trent via Lincoln came into being, although the main constituent headwaters were restricted to the Soar, the Derwent and (with less certainly) the Dove, with no direct west-to-east drainage between the Derby and Nottingham areas at that time. It was the second glaciation of the region, during MIS 8, that gave rise to a Trent system comparable with that of the present day. It was during the deglaciation of MIS 8 ice in the Middle Trent that the 'Hilton Terrace' complex was formed (now known under other names: see Table 3; Fig. 5), from which comes the artefact assemblages that were the rationale for the TVPP. Indeed, those artefacts can be shown to have been reworked, almost in their entirety, from earlier deposits and landscapes destroyed by that glaciation and are therefore not indigenous to the late MIS 8 deposits from which they were recovered (Bridgland et al., 2014).

The final element in the evolution of the Trent system, bringing it into the configuration familiar at the present day, was its diversion to the Humber, which occurred during the latest Pleistocene, coincident with Devensian deglaciation and drainage of Lake Humber.

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Table caption:

Table 1 Summary of key geochronology from the Trent sequence. Abbreviation: TL = Thermoluminescene.

Table 2 Clast-lithological data (% except where stated) from the Rauceby Gravel and related deposits, with representative Trent analyses for comparison (selected data from Bridgland et al., 2014). Abbreviations: CH – Caythorpe Heath Gravel (left-bank tributary of the Ancaster Trent); Sc – Scarle Gravel of the Lower Trent; HP – Holme Pierrepont Gravel of the Lower Trent (in all cases Gravel can be expanded to 'Sand and Gravel' and the geographical descriptor can equally be applied to the morphological 'Terrace'); u – upper; l – lower.

Table 3 Correlation and stratigraphical positions of terrace deposits and associated sediments in the wider Trent system, showing MIS attribution (modified from Bridgland *et al*., 2014). Note that the Thrussington and Oadby tills appear in both MIS 12 and MIS 8; it is indeed envisaged that these names have been applied to tills of both ages, such that they should perhaps be regarded as facies, representative of tills from western and eastern sources (respectively). Distinguishing genuine Anglian and 'Wragby' age tills, if both exist, will require detailed future investigation. ~~[This table is provided as an image; it will be redesigned for B&W, if necessary]~~

Table 4 TVPP numbered sites within Fig. 3: summary of location and evidence provided. Numbering is in approximate downstream sequence, with sites from the upper reaches omitted here (for further details, including numbered sites not listed here, see Bridgland et al., 2014).

Figure Captions:

Figure 1. The modern Trent drainage in relation to bedrock geology and the limits of Pleistocene glaciations, according to traditional interpretations (note that the Devensian Wroot ice lobe is a matter of controversy – see Straw, 2002). Modified from Bridgland et al. (2014).

Figure 2. Pre-Anglian drainage (Cromerian Complex – Early Anglian), showing the Bytham River and neighbouring systems. The Derby River (Derwent) and Hinckley River (Dove) tributaries were described by Brandon (1995) and Douglas (1980), respectively; see also Rose *et al*. (2001); Lee *at al*. (2004); the Brigstock River was described by Belshaw *et al*. (2004). Modified from Bridgland et al. (2014).

Figure 3. Long profiles of terraces in the Middle and Lower Trent (extracted from Plate 4 of Bridgland et al., 2014)). The vertical range of the Elvaston and Swarkestone channels and the Trent Trench are indicated. The Bytham Sand and Gravel sediment body, ~25 km to the south, is also plotted for comparison; note that this deposit is back-tilted between the low-uplift area around Leicester and the Middle Wreak valley around Melton Mowbray. Numbered TVPP sites from this reach of the river are indicated (pale-blue = Bytham system; grey = glacial; dark blue = main Trent; red = tributary deposit). Details of these sites appear in Table 4. ~~[This diagram will be redesigned for B&W, if necessary]~~

Figure 4. Drainage following Anglian (MIS 12) deglaciation, with inset showing reconstructed lower estuarine reach during the MIS 11 and MIS 9 interglacials, now a buried valley infilled with Wragby Till. Modified from Bridgland et al. (2014).

Figure 5. Idealized cross section through the Middle Trent sequences, showing terraces and associated glacigenic deposits (based on Bridgland *et al*. (2014)). MIS correlations are indicated (see also Table 3), as is the correlation with the classic Trent terrace sequence of Clayton (1953). For terrace nomenclature in other reaches Table 3 should be consulted.

Figure 6. Reconstructed Wragby (MIS 8) glaciation of Central England (modified from Bridgland *et al*., 2014). Eastern and western ice sheets are envisaged, as with the Anglian; also shown is the lobe that is invoked to explain the till of Oadby facies in

the Elvaston and Swarkestone channels (Brandon and Cooper, 1997), as well as low-level chalky diamicton to the south of Leicester (cf. Rice, 1968). Also indicated are glacial meltwater channels, including the Southorpe Channel of Langford (2004), and the Tottenhill delta (see text). The inset shows the location of a North Sea borehole within which MIS 8 glacial diamicton has been reported (Beets et al., 2005). A significance difference in comparison with the version of this diagram published by Bridgland et al. (2014) is that lobes of western ice impinging on the Derwent valley are envisaged here. The northernmost of these was in fact postulated by Straw and Lewis (1962), as was kindly pointed out by Allan Straw in correspondence with the authors; its delimitation draws on data provided by Dalton (1945, 1957). The southernmost accommodates low-lying till in the valley around Duffield, north of Derby.

Figure 7. Drainage subsequent to MIS 8 (Wragby) deglaciation. As shown, the course of the MIS 6 Balderton–Southrey Trent between Newark and Lincoln can be reconstructed in detail since the river was subsequently diverted away from the immediate area. The earlier Eagle Moor–Martin Trent (not illustrated here) had a straighter course upstream of Lincoln and is typically represented by outliers within the cores of Balderton incised meanders (after Bridgland et al., 2014).

Figure 8. Evolution of the Trent during the last glacial cycle (late MIS 2). A. Early phase of the Late Devensian glaciation (~ 28 ka), with the Trent flowing at the level of the Beeston Terrace, via the Lincoln Gap, its upper reaches being fed by the Irish Sea (western) ice of the Late Devensian glaciation. B. Later in the Late Devensian glaciation (~23 ka), when the Wroot ice lobe was perhaps emplaced (see, however, Fig. 1 caption); the Trent continued to flow at the level of the Beeston Terrace. C. Late in the Late Devensian glaciation (~19 ka), east-coast ice surged southwards to the Wash, blocking the Humber Gap and leading to the formation of pro-glacial Lake Humber and another pro-glacial lake in the Fen Basin; southward overflow of Lake Humber breached the watershed between the Trent and Ouse systems. D. Following deglaciation the Trent flowed to the Humber and was thus separated from the Witham system, which continues to drain the former lower Trent valley into the Fen Basin. After Bridgland et al. (2014), with data from Clark et al. (2012).

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Table 1

Terrace	Site	Stratigraphical unit	Method	Sample	Age [interpreted MIS]	References
Holme Pierrepont	Holme Pierrepont	Holme Pierrepont Sand and Gravel – organic fossils from near-basal deposits	Radiocarbon	OxA-13062	11,055 ± 45 yr BP	Howard et al. (2011)
				OxA-13063	11,080 ± 45 yr BP	Howard et al. (2011)
				OxA-13113	11,170 ± 50 yr BP	Howard et al. (2011)
	Barton-under-Needwood	Holme Pierrepont Sand and Gravel	Optically Stimulated Luminescence (OSL)	HUN 05-01	24.2 ± 3.5 ka	**TVPP**: Bridgland et al. (2014)
	Besthorpe Quarry			BES 05-01 (X2633)	25.3 ± 3.3 ka	**TVPP**: Bridgland et al. (2014)
	Girton Quarry			GIR 05-01 (X2664)	18.9 ± 1.9 ka	**TVPP**: Bridgland et al. (2014)
				GIR 05-02 (X2665)	21.0 ± 1.9 ka	**TVPP**: Bridgland et al. (2014)
	Willington Quarry	Beeston Sand and Gravel		WIL 05-01 (X2666)	44.3 ± 5.9 ka	**TVPP**: Bridgland et al. (2014)
				WIL 05-02 (X2667)	38.5 ± 5.2 ka	**TVPP**: Bridgland et al. (2014)
Beeston–Scarle–Tattershall Castle	Langford Quarry	Scarle Sand and Gravel	Optically Stimulated Luminescence (OSL)	LAN 05-01 (X2618)	30.8 ± 3.3 ka	**TVPP**: Bridgland et al. (2014)
				LAN 05-02 (X2619)	27.9 ± 2.8 ka	**TVPP**: Bridgland et al. (2014)
	Chennell's Farm, S. Scarle	Scarle Sand and Gravel		SCI 05-01 (X2620)	62.9 ± 7.5 ka	**TVPP**: Bridgland et al. (2014)
				SCI 05-02 (X2621)	45.2 ± 9.3 ka	**TVPP**: Bridgland et al. (2014)
	Tattershall Castle Pit	Overburden deposits: organic silt with temperate-climate fauna	Radiocarbon	Birm 341	43,000 +1400/-1100 yr BP	Girling (1974); Holyoak and Preece (1985)
				Birm 409	42,000 ± 1000 yr BP	Girling (1974); Holyoak and Preece (1985)
				Birm 308	>40,500 yr BP	Holyoak and Preece (1985)
				Birm 448A	30,800 ±360 yr BP	Girling (1980); Holyoak and Preece (1985)
				Birm 448B	28,000 ± 800 yr BP	Girling (1980); Holyoak and Preece (1985)
				Birm 450	39,400 ± 800 yr BP	Girling (1980); Holyoak and Preece (1985)
				Birm 753	>46,300 yr BP	Girling (1980); Holyoak and Preece (1985)
		As above; organic silt with cold-climate fauna		Birm 408	44,300 +1600/-1300 yr BP	Girling (1974); Holyoak and Preece (1985)
				Birm 309/Birm 398	42,100 +1400/-1100 yr BP	Girling (1974); Holyoak and Preece (1985)
		Woody peat (Quarry F)		Birm 260	42,000 yr BP	Girling (1980); Holyoak and Preece (1985)
	Bardon Quarry, Kirkby on Bain	Sands within Tattershall Castle terrace deposits	OSL	KOB 05/01 (X2596)	26.5 ± 4.4 ka	**TVPP**: Bridgland et al. (2014)
				KOB 05/02 (X2597)	33.7 ± 5.0 ka	**TVPP**: Bridgland et al. (2014)
	Tattershall Castle Pit, interglacial channel-fill deposits	Calcareous silt	Uranium-series	78B	76 +10/-9 ka	Ivanovich and Holyoak (1982); Holyoak and Preece (1985)
				78/91	94 +10/-9 ka	Ivanovich and Holyoak (1982); Holyoak and Preece (1985)
				78C	93 +18/-16 ka	Ivanovich and Holyoak (1982); Holyoak and Preece (1985)
				78D	101 +25/-20 ka	Ivanovich and Holyoak (1982); Holyoak and Preece (1985)
		Interglacial silts	TL	62a	114 ± 16 ka	Holyoak and Preece (1985)
		Archived fossils from the interglacial deposits	Amino-acid racemization (AAR) of *Bithynia tentaculata* opercula	Neaar 2468–2471	[MIS 5e]	**TVPP**: Bridgland et al. (2014)
	Bardon Quarry, Kirkby on Bain	Interglacial sediments, Area 3		Neaar 3306–3308	[MIS 5e]	**TVPP**: Bridgland et al. (2014)
		Interglacial sediments, Area 2		Neaar 3309	[MIS 7 – reworked ?]	**TVPP**: Bridgland et al. (2014)
				Neaar 3310–3311	[MIS 5e]	**TVPP**: Bridgland et al. (2014)
				Neaar 4135	[MIS 5e]	**TVPP**: Bridgland et al. (2014)
Balderton–Southrey	Norton Wood	Balderton Sand and Gravel	Optically Stimulated Luminescence (OSL)	NOD 05-01 (X2575)	106 ± 17 ka **(U)**	**TVPP**: Bridgland et al. (2014)
				NOD 05-02 (X2576)	108 ± 12 ka **(U)**	**TVPP**: Bridgland et al. (2014)
				NOD 05-03 (X2577)	122 ± 12 ka **(U)**	**TVPP**: Bridgland et al. (2014)
	Whisby Quarry	Balderton Sand and Gravel		WHI 05-01 (X2594)	55.4 ± 7.6 ka **(U)**	**TVPP**: Bridgland et al. (2014)
				WHI 05-02 (X2595)	31.3 ± 3.0 ka **(U)**	**TVPP**: Bridgland et al. (2014)
	Cemex Quarry, Tattershall	Silty sand; Southrey terrace of the Bain		TAT 05-01 (X2622)	116 ± 10.4 ka **(U)**	**TVPP**: Bridgland et al. (2014)
				TAT 05-02 (X2623)	156 ± 13.0 ka	**TVPP**: Bridgland et al. (2014)
				TAT 05-03 (X2624)	133 ± 21.0 ka	**TVPP**: Bridgland et al. (2014)
				TAT 05-04 (X2625)	98.9 ± 11.6 ka **(U)**	**TVPP**: Bridgland et al. (2014)
				TAT 05-05 (X2626)	112 ± 16.0 ka **(U)**	**TVPP**: Bridgland et al. (2014)
	Field House, Brough	Interglacial channel deposits within the basal Balderton–Southrey Formation	Amino-acid racemization (AAR) of *Bithynia tentaculata* opercula	Neaar 3129–3131	[MIS 7]	**TVPP**: Bridgland et al. (2014)
				Neaar 4137–4139	[MIS 7]	**TVPP**: Bridgland et al. (2014)
	Norton Bottoms, Norton Disney			Neaar 3806–3817	[MIS 7]	**TVPP**: Bridgland et al. (2014)
				Neaar 3942–3944	[MIS 7]	**TVPP**: Bridgland et al. (2014)
	Coronation Farm borehole, 6.4-6.5m depth			Neaar 39441	[MIS 7]	**TVPP**: Bridgland et al. (2014)

Table 2

System:	Ancaster Trent				Lower Trent (upstream of Lincoln)										
Terrace:	Rauceby			CH	Eagle Moor			Balderton					Sc	HP	
Locality:	Gelston	Sudbrook	Sentinel Wood	Ermine Street	Birch Holt Farm	Monson's Farm	Eagle Moor	Norton Bottoms (u)	Norton Bottoms (l)	Norton Disney (u)	Norton Disney (l)	Whisby	South Scarle	Besthorpe	Girton
Total clasts	**328**	**256**	**344**	**429**	**150**	**311**	**255**	**373**	**168**	**400**	**259**	**388**	**87**	**233**	**570**
Durable: Trent suite															
Orthoquartzite	74.1	68.4	7.3	10.3	33.3	70.1	64.3	64.0	73.2	69.0	69.9	58.8	44.8	61.8	67.5
Vein quartz	7.3	11.7	0.6	2.1	10.0	10.3	13.3	9.1	8.3	10.0	11.2	14.4	3.4	12.0	11.8
Metaquartzite	5.5	6.6	0.3	0.9	5.3	5.5	9.4	8.0	0.6	9.3	5.8	6.2	2.3	4.3	5.8
Schorl	0.6	1.2			0.7		0.4	0.5	2.4		0.4		2.3	0.4	1.1
Carboniferous chert	2.4	3.5	1.2	0.5	18.7	4.5	3.9	6.7	4.2	7.0	6.6	12.6	27.6	13.7	7.0
Orthoqu. : Carb. chert (n:1)	**30.4**	**19.5**	**6.1**	**20.6**	**1.8**	**15.6**	**16.5**	**9.6**	**17.4**	**9.9**	**10.6**	**4.7**	**1.6**	**4.5**	**9.6**
Glacial indicators / Exotic															
Flint (total)			8.2	11.5	15.3	6.7	3.9	4.3	6.5	2.3	3.1	6.2	6.9	3.4	1.6
nodular			1.2	0.5		0.3									
beach			0.3	4.0											
weathered			6.7	6.5	15.3	6.1	3.9	4.3	6.5	2.3	3.1	6.2	6.9	3.4	1.6
broken				0.5		0.3									
Rhaxella chert								0.3						0.4	
Other (incl. indet.) chert			1.2		2.0	1.0					1.2				
Igneous (undifferentiated)															
Coarse	0.3														
Medium						0.3					0.4	0.3			0.2
Fine					0.7									0.4	
Porphyry					0.7	0.3	0.4						1.1		
Metamorphic					0.7										
Other crystalline		0.4			0.7	0.3		1.3		0.3					
Local / uncertain origin															
Limestone	1.2	1.6	73.5	65.5				2.1							
Calcareous sst (inc. Spilsby)			0.9	4.4											
Arkose	1.2	0.4			2.7	0.3		1.1		0.5	0.4	0.3		0.4	0.2
Other sandstone	1.2	3.2	1.2	0.2	7.3	0.3	2.4	1.1	3.0	0.8	0.8	1.0	6.8	1.3	2.6
Gryphaea fossils				1.9				0.3							
Skerry									0.6	0.5	0.4	0.3	3.4	1.7	
Chalk				1.2											
Ironstone	6.1	3.1	5.8	1.6		0.3	1.2	0.5	1.2						1.1
Semi-durable local ssts															
Other					2.0			2.1		0.6			1.1		1.2

Table 3

MIS		PALAEO-GEOGRAPHY	UPPER TRENT	Middle Trent: DERWENT	Middle Trent: SOAR	Middle Trent: TRENT	TRENT TRENCH	Lower Trent via Lincoln: TRENT	Lower Trent via Lincoln: WITHAM	Lower Trent via Lincoln: BAIN	YORKSHIRE OUSE	MIS
1		HUMBER TRENT HOLOCENE	Holocene alluvium	Holocene alluvium	Holocene alluvium	Holocene alluvium	Holocene alluvium	Holocene alluvium	Holocene alluvium	Holocene alluvium	Holocene alluvium	1
				Ambaston	Quorndon	Hemington		Separate Witham drainage	Separate Witham drainage	Lake Humber	Post-glacial sequence	
2	DEVENSIAN	Glaciation of uppermost and lowermost Trent Upper Trent / Lower Trent	First Terrace	Belper*	Syston	Holme Pierrepont	Holme Pierrepont	Holme Pierrepont (Diverges northward: diverted to the Humber)	Buried	Buried	Vale of York glaciation	2
			Second Terrace								Holme Pierrepont via the Humber	
3			Whitemoor Haye						Upper TC deposits?			3
4				Ambergate[+] - Allenton	Wanlip	Beeston	Bassingfield	Scarle	Tattershall Castle	Tattershall Castle		4
5a									Upper TC deposits?			5a
5d–5b									Tattershall Castle			5d–5b
5e		IPSWICHIAN		Crown Inn Boulton Moor					Fulbeck / TC	Tattershall Castle	Austerfield	5e
6	LATE MIDDLE PLEISTOCENE	TRENT via LINCOLN (Fig. 2c)	NO PRESERVATION	Borrowash	Lower Birstall	Egginton Common	NO PRESERVATION	Balderton	Southrey	Tattershall Thorpe	Basement Till?	6
7						Terrace Complex		Norton Bottoms	Coronation Farm	Tattershall Thorpe	Bielsbeck	7
8				Ockbrook	Middle Birstall	Etwall		Eagle Moor (lower facet)	Martin (lower facet)		NO PRESERVATION	8
				Downcutting enhanced by glacio-isostasy				Downcutting enhanced by glacio-isostasy				
				Little Eaton	Upper Birstall	Sandiacre		Eagle Moor (upper facet)	Martin (upper facet)			
		WRAGBY GLACIATION		Matlock	Knighton	Hilton Chellaston (outwash gravels)		Outwash Skellingthorpe Clay (glacial lake)	WRAGBY TILL	WRAGBY TILL[#]	Basement Till?	
				(Thrussington facies)	TILL	(Oadby facies)						
9		SOAR–TRENT via LINCOLN (Fig. 2b)		Hathern gravel		Elvaston and Swarkestone Channels						9
10												10
11												11
				Downcutting enhanced by glacio-isostasy				Downcutting enhanced by glacio-isostasy				
12	ANGLIAN			High Tor		Wilford HIll (outwash)						12
		ANGLIAN GLACIATION	TILL (Thrussington facies)				TILL (Oadby facies)					
17–13	CROMERIAN	BYTHAM RIVER		Putative deposits of the 'Derby River'	Baginton–Bytham Sand and Gravel			ANCASTER RIVER DEPOSITS Rauceby and Caythorpe Heath gravels				17–13

* See Chapter 2.4.1.5. Termed Chaddesden Sidings in the Lower Derwent by the BGS, although no outcrops are so named on DiGMap

[+] See Chapter 2.4.1.5. Waters and Johnson (1958) name retained for Middle and Upper Derwent system

[#] The Calcethorpe Till of Straw (1983) also occurs in the Bain Valley, upstream of the Tattershall area

Table 4

Number	Name	NGR	Characteristics
3	Huncote	SP 502975	Bytham Sand and Gravel beneath till
4	Brooksby	SK 670160	Bytham Sand and Gravel in Wreake valley
5	Castle Bytham	SK 180187	Bytham Sand and Gravel, type locality
6	Wilford Hill	SK 582352	Hill-capping gravel, glacial outwash
8	Sentinel Wood (Rauceby)	SK 997461	Rauceby Gravel (Ancaster Trent)
9	Ermine Street	SK 988471	Caythorpe Heath Gravel
10	Sudbrook	SK 983453	Rauceby Gravel, degraded outlier
11	Gelston	SK 917456	Rauceby Gravel, upstream outlier
12	Little Ponton	SK 905334	Glacial outwash
15	Barkby Thorpe	SK 632084	Knighton 'terrace' of Soar (cf. Rice, 1968)
16	East Leake	SK 558248	Knighton 'terrace'; contra White et al. (2008)
17	Barkby	SK 634101	Upper Birstall Terrace of Soar
19	Breaston	SK 462345	Sandiacre Gravel
20	Hilton	SK 252317	Etwall Sand and Gravel; Hilton SSSI
22	Stenson	SK 328302	Etwall Sand and Gravel
23	Willington	SK 278273	Beeston Sand and Gravel
24	Barrow upon Trent	SK 345285	Holme Pierrepont and Hemington Sand and Gr
25	Shardlow Quarry	SK 445295	Holme Pierrepont and Hemington Sand and Gr
26	Holme Pierrepont	SK 625384	Holme Pierrepont Sand and Gravel, type locali
27	Crown Inn (Derwent)	SK 370326	Allenton Terrace of the Derwent
28	Boulton Moor (Derwent)	SK 380320	Allenton Terrace of the Derwent
29	Shelton Lodge Farm (Smite)	SK 768438	Whatton Sand and Gravel; existence doubtful
30	Scarrington (Smite)	SK 737413	Smite terrace gravels, low terrace
31	Aslockton (Smite)	SK 750407	Whatton Sand and Gravel; existence confirme
32	Birch Holt Farm	SK 868608	Eagle Moor Sand and Gravel, upper facet
33	Eagle Moor	SK 889682	Eagle Moor Sand and Gravel, upper facet
34	Monson's Farm	SK 923703	Eagle Moor Sand and Gravel, lower facet
35	Norton Bottoms	SK 863588	Balderton Sand and Gravel
36	Field House	SK 851953	Balderton Sand and Gravel
37	Holly Farm	SK 841585	Balderton Sand and Gravel
38	Norton Wood	SK 883605	Balderton Sand and Gravel
39	Whisby	SK 897669	Balderton Sand and Gravel
40	South Scarle	SK 856639	Scarle Sand and Gravel
41	Besthorpe	SK 822632	Holme Pierrepont Sand and Gravel
42	Girton	SK 827683	Holme Pierrepont Sand and Gravel
43	Langford	SK 820602	Scarle Sand and Gravel
44	Bardney	TF 132690	Southrey Sand and Gravel overlying Wragby Ti
45	Tattershall Cemex (Bain)	TF 211610	Bain terrace gravels
46	Kirkby on Bain (Bain)	TF 233607	Bain terrace gravels
54	Bassingham Fen	SK 939602	Palaeo-Witham deposits (cf. Howard et al., 19
55	Potterhanworth.	TF 069675	Martin Sand and Gravel (upper and lower face

Figure 1

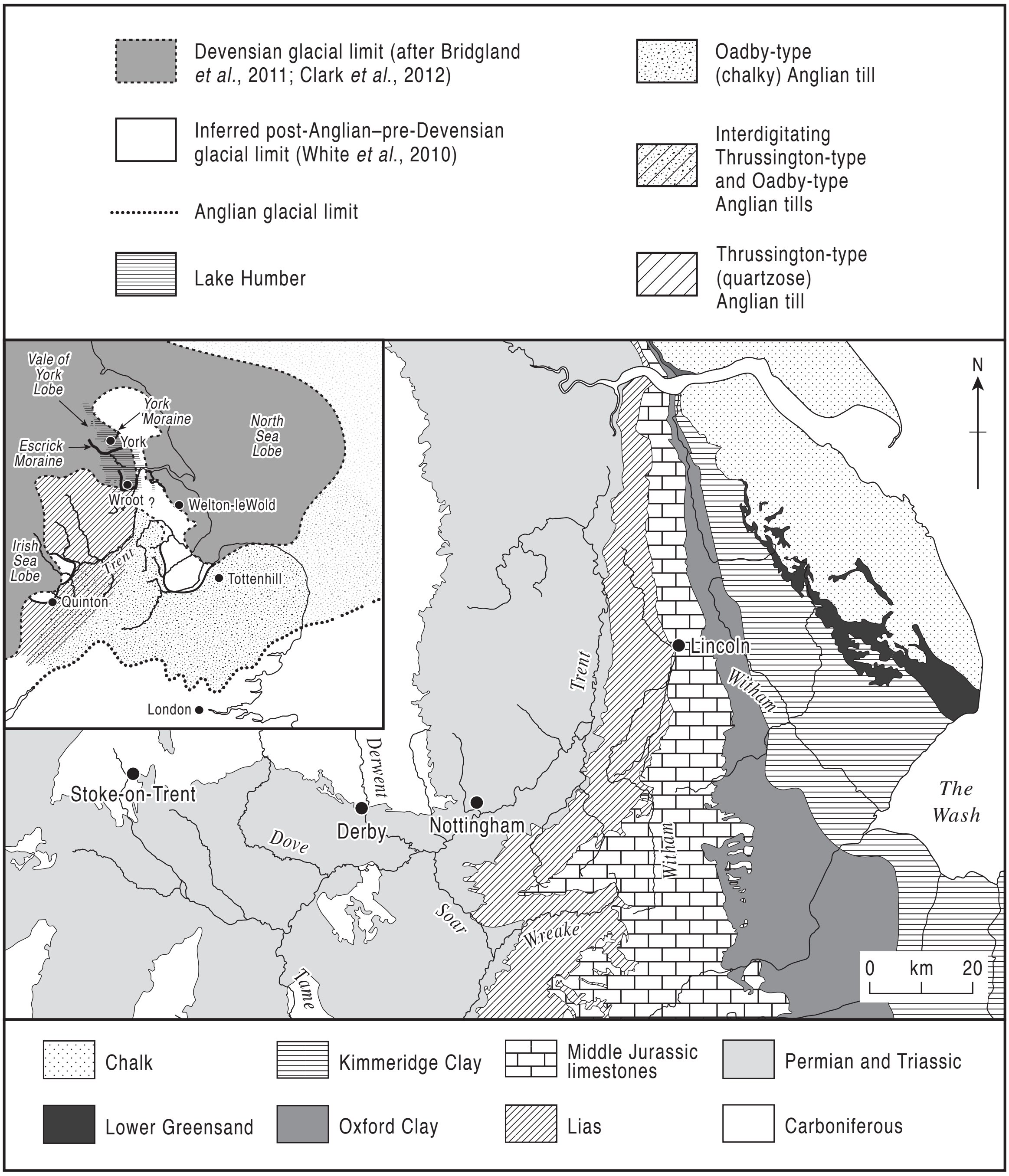
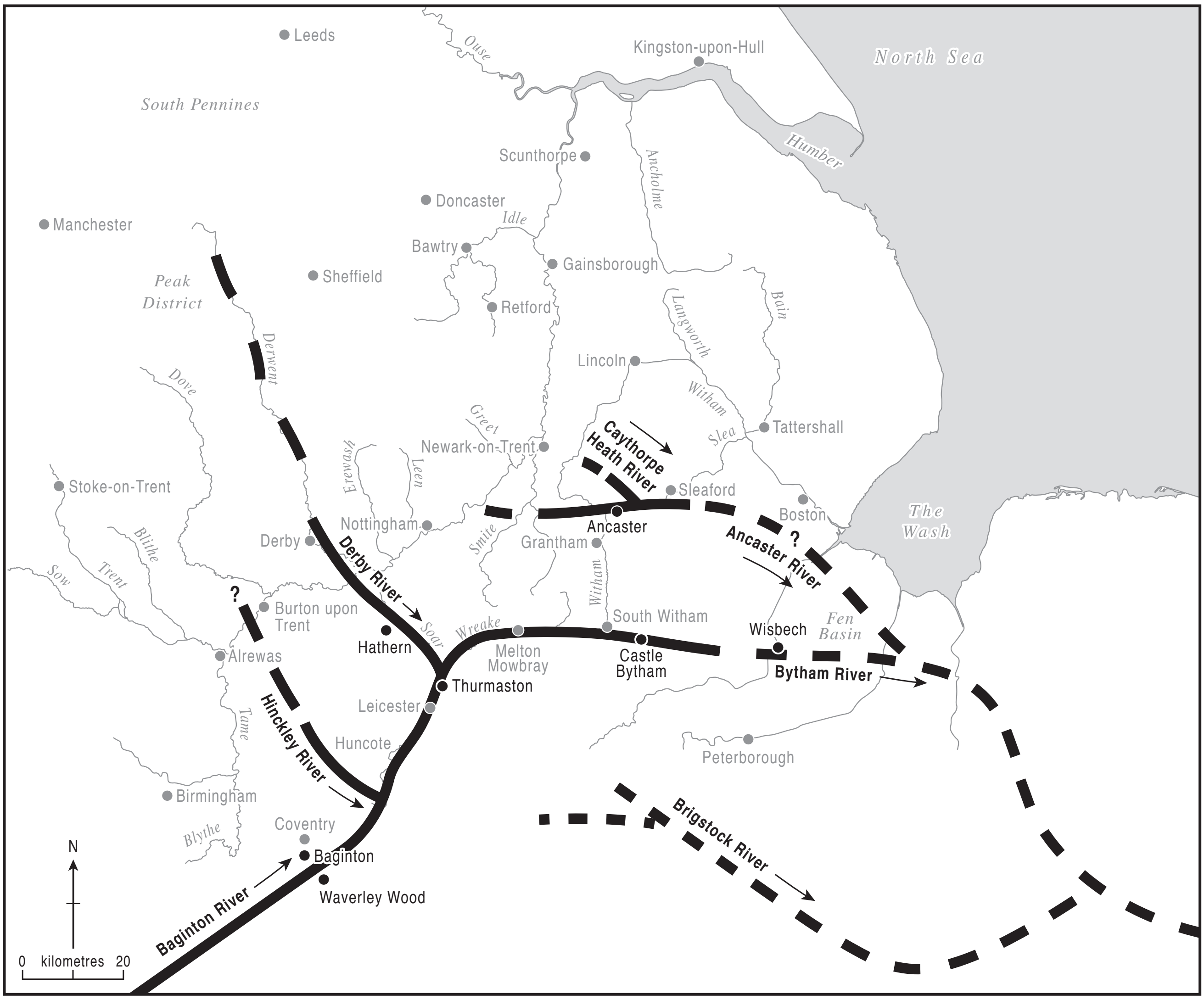

Devensian glacial limit (after Bridgland et al., 2011; Clark et al., 2012)
Inferred post-Anglian–pre-Devensian glacial limit (White et al., 2010)
Anglian glacial limit
Lake Humber
Oadby-type (chalky) Anglian till
Interdigitating Thrussington-type and Oadby-type Anglian tills
Thrussington-type (quartzose) Anglian till
Vale of York Lobe
York Moraine
York
Escrick Moraine
North Sea Lobe
Wroot
?
Welton-leWold
Irish Sea Lobe
Trent
Tottenhill
Quinton
London
N
Lincoln
Witham
Trent
The Wash
Stoke-on-Trent
Derwent
Derby
Nottingham
Dove
Soar
Wreake
Tame
0 km 20
Chalk
Kimmeridge Clay
Middle Jurassic limestones
Permian and Triassic
Lower Greensand
Oxford Clay
Lias
Carboniferous

Figure 2



Leeds
South Pennines
Ouse
Kingston-upon-Hull
North Sea
Humber
Scunthorpe
Ancholme
Doncaster
Manchester
Idle
Bawtry
Gainsborough
Peak District
Sheffield
Retford
Bain
Langworth
Derwent
Lincoln
Dove
Witham
Greet
Tattershall
Slea
Caythorpe Heath River
Newark-on-Trent
Erewash
Leen
Stoke-on-Trent
Sleaford
Boston
Nottingham
Ancaster
Blithe
Derby
Smite
Grantham
Ancaster River
The Wash
Derby River
Sow
Trent
Witham
Burton upon Trent
South Witham
Fen Basin
Soar
Wreake
Wisbech
Hathern
Melton Mowbray
Castle Bytham
Alrewas
Bytham River
Thurmaston
Leicester
Hinckley River
Tame
Huncote
Peterborough
Birmingham
Brigstock River
Coventry
Blythe
Baginton
N
Waverley Wood
Baginton River
0 kilometres 20

Figure 3

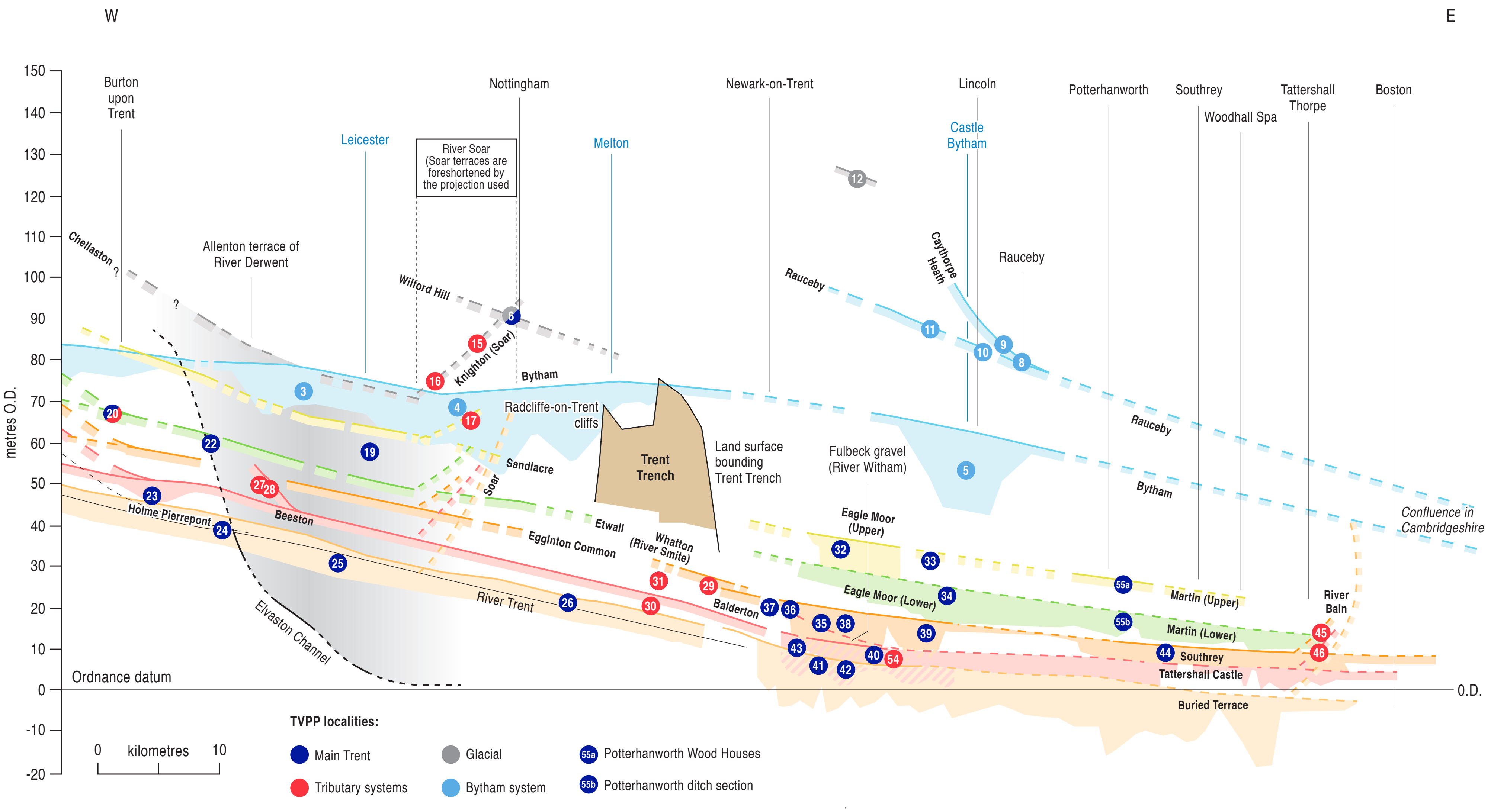
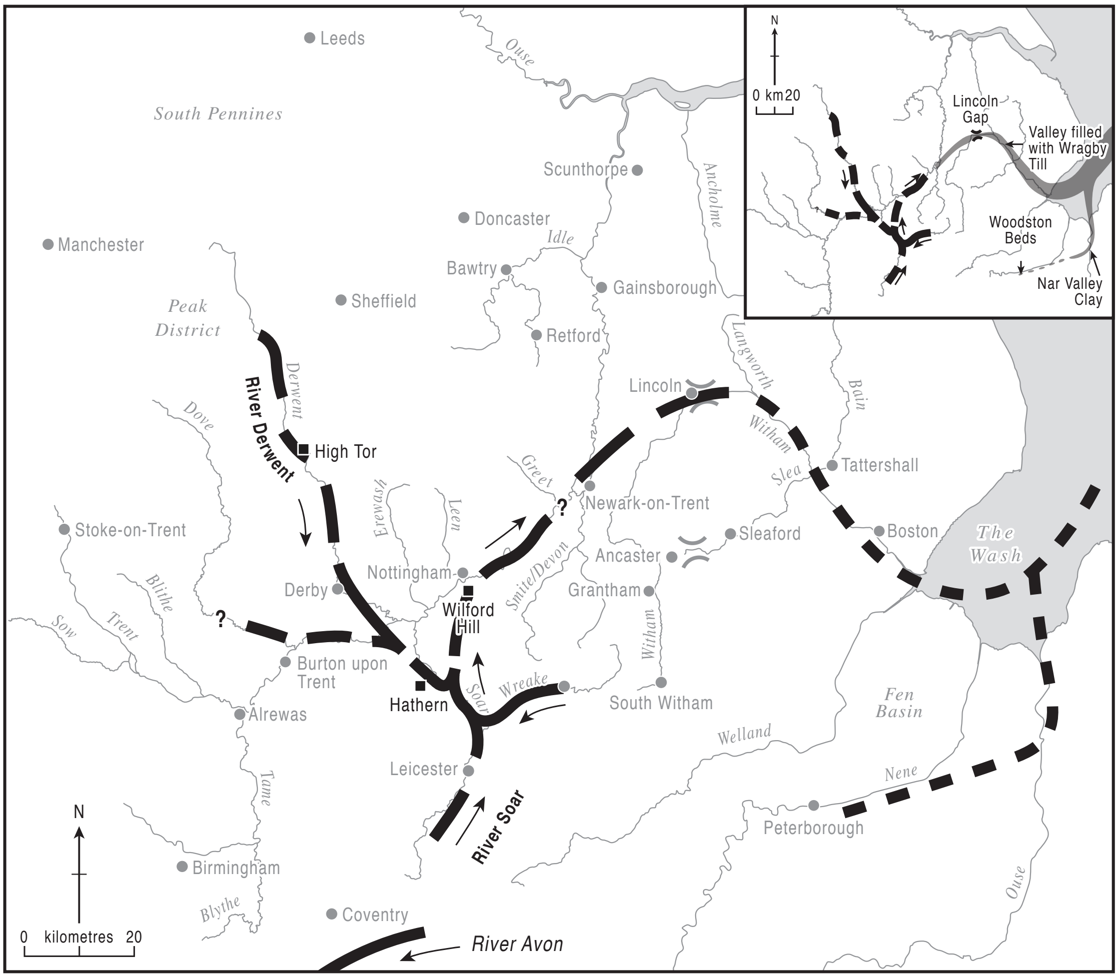
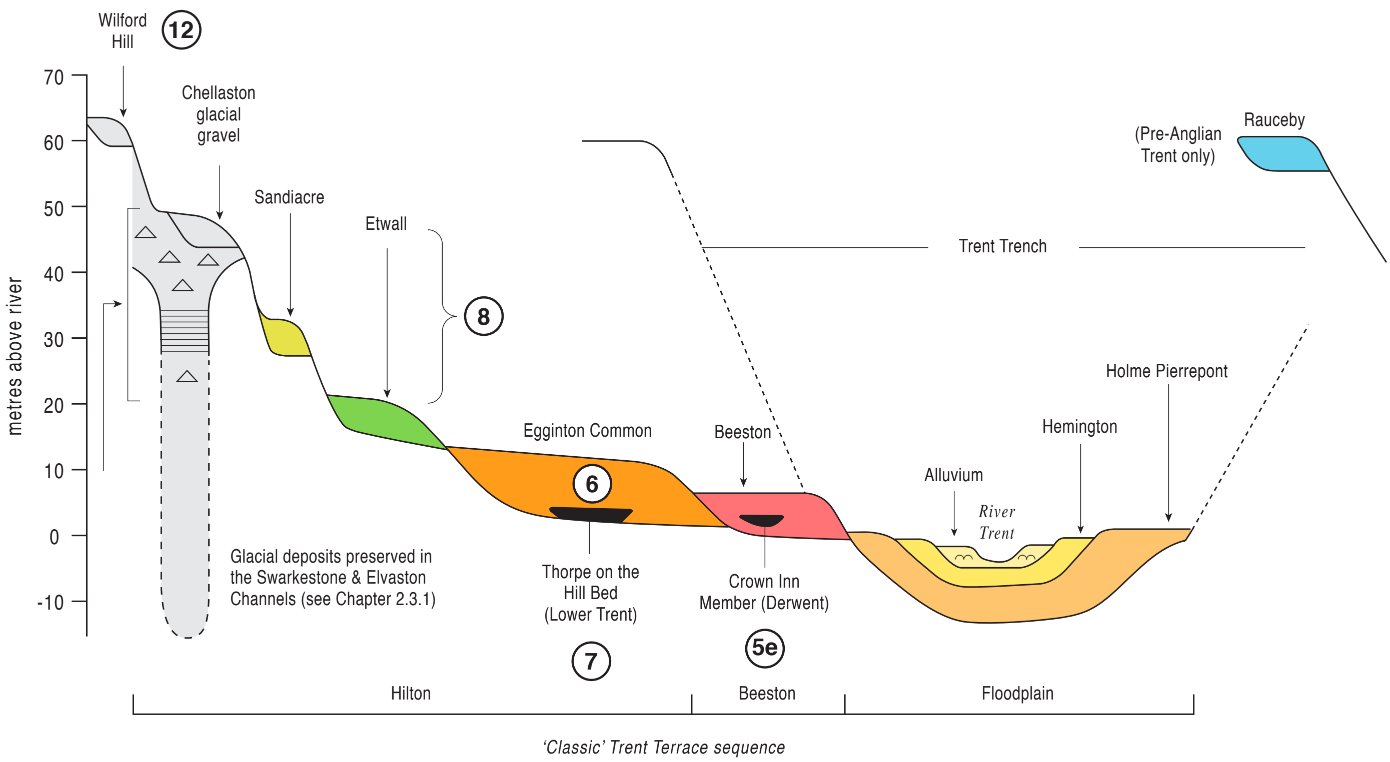

W
E
metres O.D.
Burton upon Trent
Nottingham
Newark-on-Trent
Lincoln
Potterhanworth
Southrey
Woodhall Spa
Tattershall Thorpe
Boston
Leicester
Melton
Castle Bytham
River Soar (Soar terraces are foreshortened by the projection used
Chellaston
Allenton terrace of River Derwent
Wilford Hill
Knighton (Soar)
Bytham
Radcliffe-on-Trent cliffs
Trent Trench
Land surface bounding Trent Trench
Fulbeck gravel (River Witham)
Rauceby
Caythorpe Heath
Sandiacre
Soar
Etwall
Egginton Common
Whatton (River Smite)
Beeston
Holme Pierrepont
River Trent
Balderton
Eagle Moor (Upper)
Eagle Moor (Lower)
Martin (Upper)
Martin (Lower)
Southrey
Tattershall Castle
Buried Terrace
River Bain
Confluence in Cambridgeshire
Elvaston Channel
Ordnance datum
O.D.
kilometres
TVPP localities:
Main Trent
Tributary systems
Glacial
Bytham system
Potterhanworth Wood Houses
Potterhanworth ditch section

Figure 4



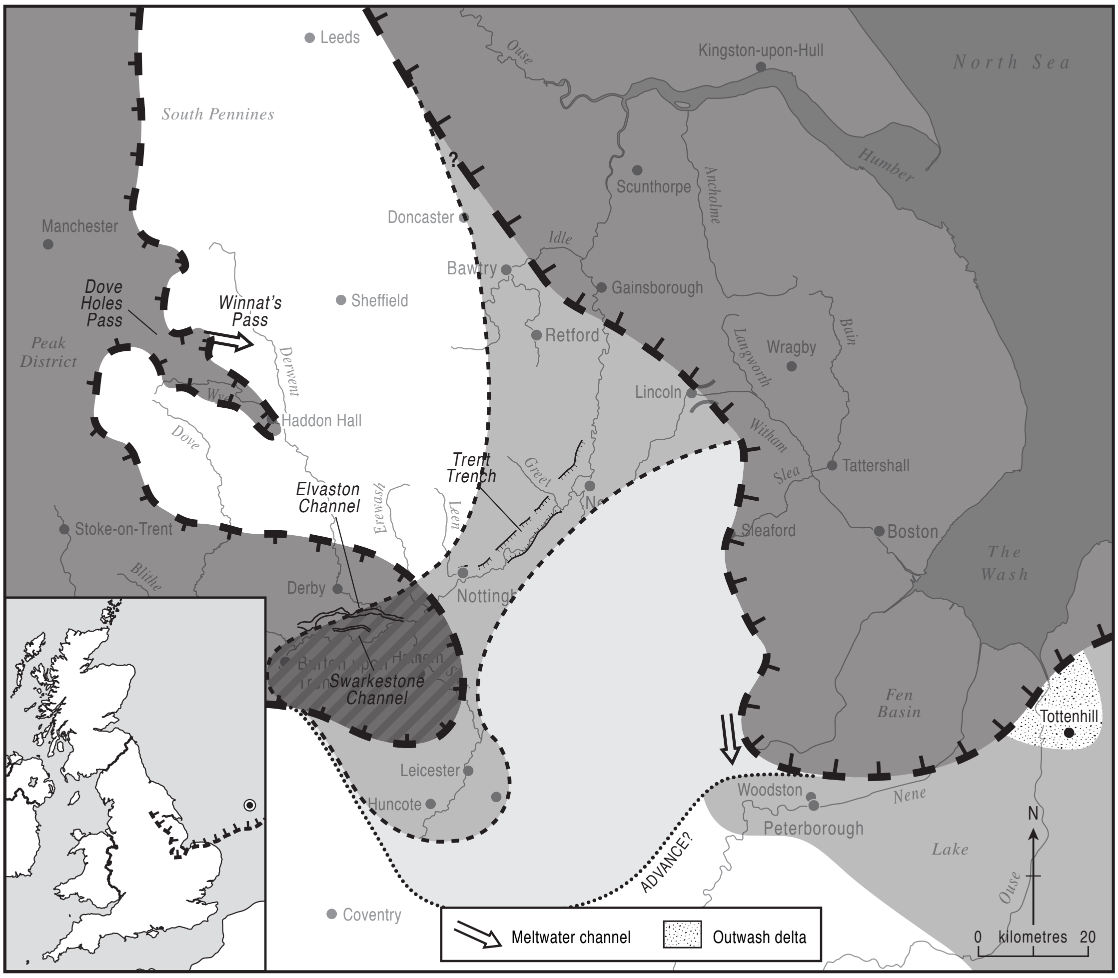
Leeds
South Pennines
Ouse
Scunthorpe
Doncaster
Manchester
Idle
Bawtry
Gainsborough
Ancholme
Sheffield
Peak District
Retford
Derwent
River Derwent
High Tor
Dove
Lincoln
Langworth
Bain
Witham
Tattershall
Slea
Greet
Newark-on-Trent
Boston
Stoke-on-Trent
Erewash
Leen
?
Sleaford
The Wash
Ancaster
Nottingham
Smite/Devon
Derby
Grantham
Blithe
Wilford Hill
Sow
Trent
Burton upon Trent
Witham
Wreake
Hathern
Soar
South Witham
Fen Basin
Alrewas
Welland
Leicester
Tame
Nene
River Soar
Peterborough
N
Birmingham
Ouse
Blythe
Coventry
0 kilometres 20
River Avon
N
0 km 20
Lincoln Gap
Valley filled with Wragby Till
Woodston Beds
Nar Valley Clay

Figure 5



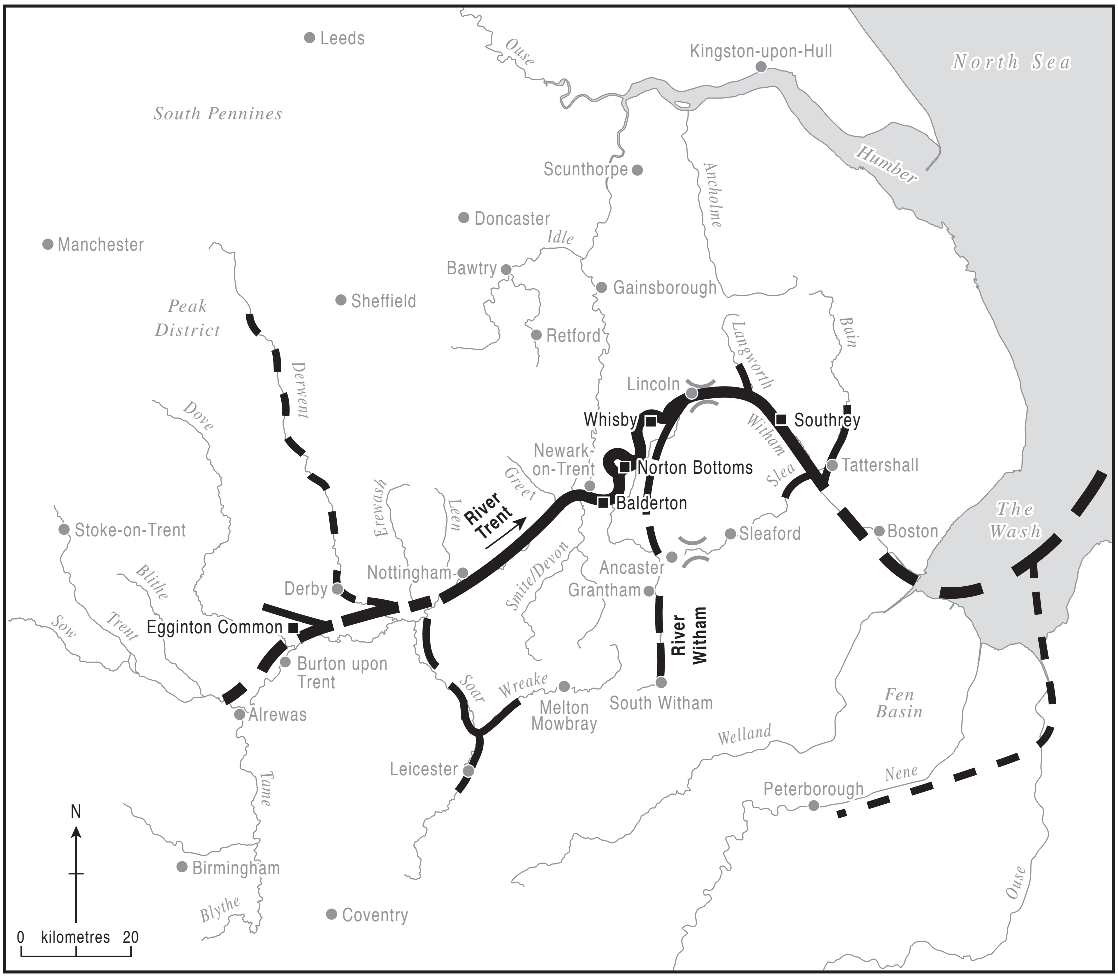
Wilford Hill
12
Chellaston glacial gravel
Sandiacre
Etwall
8
Egginton Common
6
Beeston
Trent Trench
(Pre-Anglian Trent only)
Rauceby
Holme Pierrepont
Hemington
Alluvium
River Trent
Glacial deposits preserved in the Swarkestone & Elvaston Channels (see Chapter 2.3.1)
Thorpe on the Hill Bed (Lower Trent)
7
Crown Inn Member (Derwent)
5e
metres above river
70
60
50
40
30
20
10
0
-10
Hilton
Beeston
Floodplain
'Classic' Trent Terrace sequence

Figure 6



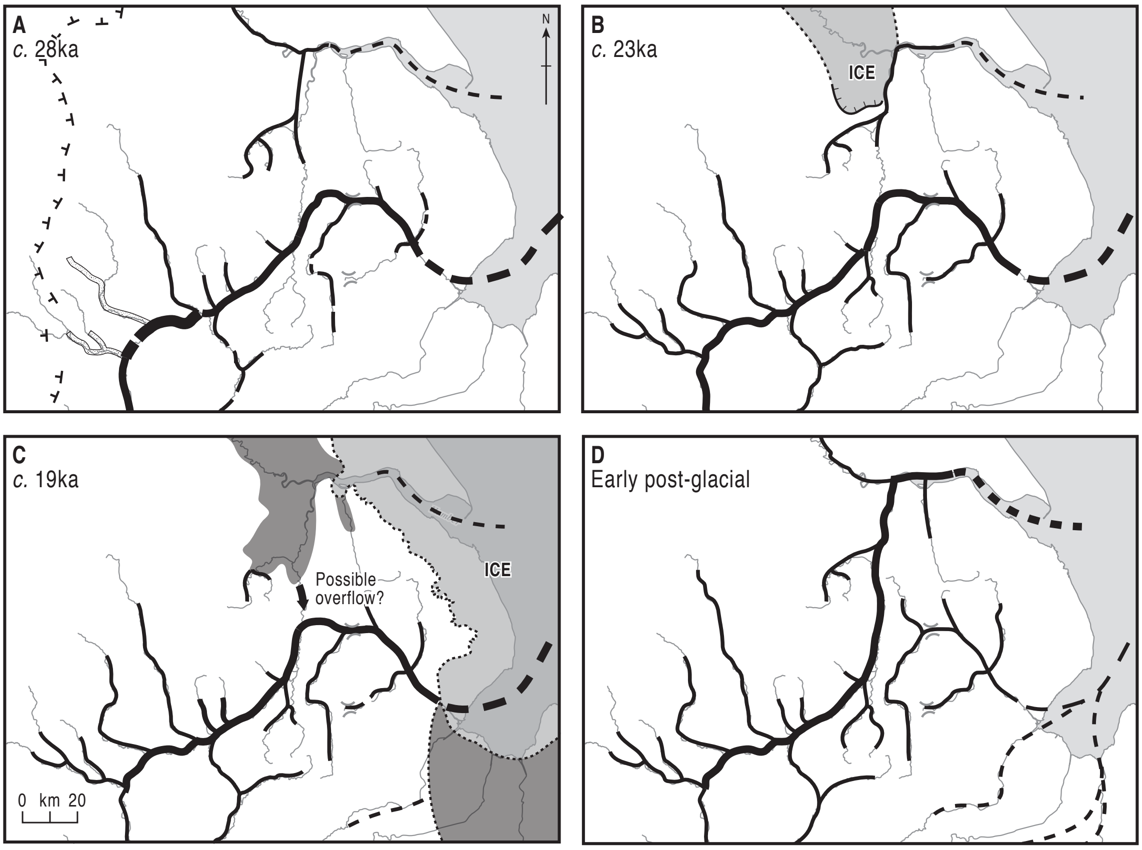
Leeds
South Pennines
Kingston-upon-Hull
North Sea
Ouse
Humber
Scunthorpe
Ancholme
Manchester
Doncaster
Idle
Bawtry
Gainsborough
Dove Holes Pass
Winnat's Pass
Sheffield
Retford
Bain
Wragby
Langworth
Peak District
Derwent
Lincoln
Haddon Hall
Witham
Dove
Trent Trench
Greet
Slea
Tattershall
Elvaston Channel
Erewash
Leen
Stoke-on-Trent
Sleaford
Boston
The Wash
Blithe
Derby
Swarkestone Channel
Fen Basin
Tottenhill
Leicester
Woodston
Nene
Huncote
Peterborough
N
Lake
ADVANCE?
Ouse
Coventry
Meltwater channel
Outwash delta
0 kilometres 20

Figure 7



Leeds
Kingston-upon-Hull
North Sea
South Pennines
Ouse
Humber
Scunthorpe
Ancholme
Doncaster
Manchester
Idle
Bawtry
Gainsborough
Peak District
Sheffield
Retford
Langworth
Bain
Derwent
Lincoln
Dove
Whisby
Southrey
Witham
Newark-on-Trent
Norton Bottoms
Tattershall
Greet
Slea
Erewash
Leen
River Trent
Balderton
Stoke-on-Trent
Sleaford
Boston
The Wash
Smite/Devon
Ancaster
Blithe
Nottingham
Derby
Grantham
Sow
Trent
Egginton Common
River Witham
Burton upon Trent
Soar
Wreake
South Witham
Fen Basin
Alrewas
Melton Mowbray
Welland
Leicester
Peterborough
Nene
Tame
N
Birmingham
Blythe
Coventry
Ouse
0 kilometres 20

Figure 8



A
c. 28ka
N
B
c. 23ka
ICE
C
c. 19ka
Possible
overflow?
ICE
0 km 20
D
Early post-glacial